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Canadian Atlantic Fisheries
Scientific Advisory Committee

CAFSAC Research Document 88/14

Comité scientifique consultatif des
pêches canadiennes dans d'Atlantique

CSCPCA Document de recherche 88/14

Consideration of Snow Crab Yield Per Recruit Incorporating Terminal Molt and a Differential Harvesting Strategy

by

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Abstract.

A yield per recruit model is presented as an adjunct to the assessment for Atlantic coast Cape Breton snow crab. The assessment posed a harvesting strategy which preferentially exploited males in terminal molt status. A potential method for such preferential exploitation is a ring which sets a minimal chelal diameter limit as opposed to the current limitation based on minimum carapace width (CW). As is standard for yield per recruit analysis, the model incorporates growth and mortality rates. However, growth in snow crab must include the probability of entering terminal molt over a wide size range. The model presented allows for fishing mortalities to be applied independently to terminal and non-terminal animals.

The model crab stock was comprised of five molt classes of: 75, 90, 108, 130 and 156 mm CW. The natural mortality was 0.2 for all animals and the probability of molting was 0.8 per year for all animals. "Skip molting" was not included in the model. Two selectivities were assessed with partial recruitments of 0, 0.2, 1, 1, 1 and of 0.6, 0.8, 1, 1, 1 which correspond approximately to 95 and 75 mm CW retentions. The former selectivity is the current legal minimum size and the other allows scope for preferential harvesting of terminal animals.

The model analytically solves for the stable size and proportion terminal distributions. Equilibrium yield and biomass were calculated for each pair of terminal and non-terminal fishing mortalities. F_{max} and $F_{0.1}$ and their respective yields (Y) for non-discriminant fishing of terminal and non-terminal males are:

Selectivity	F_{max}	$Y(F_{max})$	$F_{0.1}$	$Y(F_{0.1})$
95 mm	0.92	21.3	0.35	18.6
75 mm	0.53	19.3	0.30	19.0

The estimate of $F_{0.1}$ at the current minimum size is approximately one half the CAFSAC recommended exploitation rate of 50% (= an F of 0.69). Equilibrium biomass was considerably more sensitive to fishing non-terminal compared to terminal males. Yields could be improved at relatively little cost to equilibrium biomass by preferentially fishing terminal males. This in effect is more pronounced with the 75 mm CW selectivity and lower F levels.

Résumé

Un modèle du rendement par recrue est présenté comme complément à l'évaluation de la pêcherie de crabe des neiges du Cap-Breton, sur la côte atlantique. L'évaluation proposait une stratégie qui favorisait l'exploitation des mâles en phase de dernière mue. Cette exploitation préférentielle pourrait faire appel à un anneau fixant comme limite du un diamètre minimal de la pince, par opposition à la méthode actuelle fondée sur la largeur de la carapace. Comme il est d'usage dans l'analyse du rendement par recrue, le modèle tient compte des taux de croissance et de mortalité. Cependant, pour la croissance, il faut tenir compte de la probabilité d'entrée dans la phase de dernière mue dans une grande plage de taille. Le modèle permet d'appliquer la mortalité par pêche indépendamment du fait que les crabes sont ou non en phase de dernière mue.

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Le stock de crabes modélisé se composait de cinq classes de mue : 75, 90, 108, 130 et 156 mm de largeur de la carapace. La mortalité naturelle était de 0,2 pour tous les animaux et la probabilité de muer de 0,8 par an. Le modèle ne tenait pas compte de la possibilité de sauter une mue. On a évalué deux sélectivités avec recrutements partiels de 0, 0,2, 1, 1, 1 et de 0,6, 0,8, 1, 1, 1, qui correspondent approximativement à des tailles de 95 et 75 mm de largeur de la carapace. Dans le premier cas, la sélectivité correspond à la taille légale minimale, et dans l'autre elle permet l'exploitation préférentielle des animaux en phase de dernière mue.

Le modèle résoud analytiquement les distributions stables de la taille et de la proportion chez les crabes en phase de dernière mue. Le rendement et la biomasse à l'équilibre ont été calculés pour chaque paire de mortalités par pêche en phase ou non de dernière mue. F_{max} et $F_{0,1}$ et leurs rendements respectifs (Y) pour une pêche non sélective des mâles en phase ou non de dernière mue sont les suivants:

sélectivité	F_{max}	$Y(F_{max})$	$F_{0,1}$	$Y(F_{0,1})$
95 mm	0,92	21,3	0,35	18,6
75 mm	0,53	19,3	0,30	19,0

L'estimation de $F_{0,1}$ à la taille minimale actuelle correspond à environ la moitié du taux d'exploitation de 50 % recommandé par le CSCPCA (F de 0.69). La biomasse à l'équilibre est nettement plus sensible à la pêche des mâles qui ne sont pas en phase de dernière mue qu'à celle des mâles en phase de dernière mue. On pourrait améliorer les rendements sans trop affecter la biomasse à l'équilibre en pêchant sélectivement les mâles en phase de dernière mue. Cet effet est plus prononcé avec la sélectivité à 75 mm de largeur de la carapace et avec des niveaux de pêche plus faibles.

Introduction.

The purpose of this study is to develop a yield per recruit model which considers terminal molt to maturity over a wide size range. Having developed such a model we can then test the gross relative consequences of a chelal ring mechanism that differentially culls individuals at terminal ecdysis and leaves unscathed those individuals that retain the propensity to grow . The exercise was provoked by the observation of Elner et al. (1988) that a large proportion of the trapable male biomass of snow crab off eastern Cape Breton Island appears comprised of pygmy males, animals in terminal molt below the legal minimum size (See Figure 1). Not only does this terminal "sink" represent a wasted resource but it has the potential to depress production by sucking-in scarce resources that might otherwise benefit upcoming younger and growing animals. The only known positive benefit of "sink" males might be to provide partners for mating females in the absence of larger males; however, even if such were the case, there is a danger that the pygmy males could produce strong selective pressures for dwarfism in the snow crab stocks. Clearly, as an experiment, even on purely ecological grounds, there appears sound rational for cleansing some stocks of accumulated pygmy males. We believe that the following model produces

further support for the experiment based on yield per recruit projections.

Methods.

A model was developed to extend the classical yield per recruit calculation to apply to a stock which has the gross characteristics of snow crab growth and mortality. That is terminal molting over a range of molt classes, differential rates of molting and a potential differential fishing mortality on terminal and non-terminal males. The calculation determines the stable age and size distribution for a given set of descriptive and fishing parameters. The logic behind the model is a balance of flows into and out of each molt class. The influx is "white" crabs from the next smaller class. Once the animals molt in, there is a probability of dying, a probability of molting to the next class, a probability of being caught and a probability of having undergone terminal ecdysis. The model solves the distribution of animals analytically but was checked against a less sophisticated model which iteratively solves for the equilibrium distribution.

The novel attribute of our yield per recruit model is the ability to discriminate between fishing mortality applied to males in terminal and non-terminal molt status. This allows a theoretical investigation of the impact of harvesting strategies which focus on one or the other sectors of the population.

The descriptive parameters chosen were a natural mortality of 0.2 for all molt classes and a probability of molting of 0.8 for all non-terminal males. Weight for each class is from Bailey (1978) and corresponds to mean molt class sizes of 75, 90, 108, 130 and 156 mm carapace width. Two trap selectivity patterns were chosen. One corresponds to current fishing on males above 95 mm CW (0, 0.2, 1, 1, 1 for the respective size classes) the other is to represent an experimental shift to retaining smaller animals (0.6, 0.8, 1, 1, 1).. Although the model was defined to enable the consideration of skip molting, this attribute was not used in the present study. The outputs from the model are equilibrium yield per recruit and equilibrium (male) biomass per recruit. The outputs are broken down into contributions from terminal and non-terminal males as well as the total.

For information, the computer program (in APL) which was used is listed in Appendix A.

Results.

The results of the calculations are summarized in Tables 1, 2 and 3. The first table contains the yields for various ranges of fishing mortalities. It is partitioned into three sub-tables. The uppermost is the yield from non-terminal males, the middle is yield from terminal males and the bottom is the sum of the upper two. The same format is used in Table 2 which displays the equilibrium biomass. The range of F utilized extends from zero to an annual rate of 2. F on the terminal

males varies over the columns and for the non-terminals over the rows. Table 3 contains only total yield and biomass when the selectivity is set to catch smaller animals.

An examination of Table 1.a shows that increasing F on the non-terminal animals increases yield (viz. any column of Table 1.a). Changing the fishing mortality on terminal males (FT) has no affect on the non-terminal yield as would be expected in a model which does not include recruitment. The yield is seen to reach a plateau at an FN , the fishing mortality on non-terminal males, of approximately 0.8. Table 1.b shows the yield from terminal males. It shows the interdependence of fishing mortality on both terminal and non-terminal animals. The yield of terminals increases monotonically with increasing effort against them but is highly dependent on the fishing mortality on the non-terminals. The total yield is dominated by the contribution of non-terminal animals. It reaches a plateau when FN is in the range of 0.6 to 0.8 depending upon the value of.the less sensitive FT.

The diagonals in Table 3 correspond to fishing the animals in proportion to their abundance. A strategy, such as the use of a chelal ring, that preferentially harvests terminal animals, would be reflected as departures from the diagonal to the right of the yield table.

Table 2 shows the equilibrium biomasses. The non-terminal males are always the larger proportion of the biomass under steady state conditions. The biomass is seen to be much more sensitive to FN dropping almost twice as far under the simulated range as it does when FT is varied. (75.6 versus 138.9 from a virgin level of 200.6 .)

Table 3 displays the total yield and biomass when the selectivity is changed to approximate a 75 mm CW retention limit of the gear. As expected the yield peaks at lower FN's, at about .8 when FT is zero to about .4 when FT is 2. Preferential harvesting of terminal males has a more dramatic effect than was seen in Table 1 Also, the sensitivity of the biomass to non-terminal fishing mortality is much higher than the sensitivity to the exploitation of terminal animals and the difference is more pronounced than was seen in Table 2.

The following table contains F_{max} and $F_{0.1}$ for the two trial selectivities when fishing is proportional to abundance.

Selectivity	F_{max}	$Y(F_{max})$	$F_{0.1}$	$Y(F_{0.1})$
95 mm	0.92	21.3	0.35	18.6
75 mm	0.53	19.3	0.30	19.0

Discussion.

A yield per recruit model has been successfully developed to examine the effects of terminal molt to maturity over a wide size range and the effects of a differential harvest. While the results of the model appear to confirm one's intuitive understanding, the model affords the first analytical investigation of this question.

The traditional target fishing mortality of $F_{0.1}$ with the 95 mm CW size limit is estimated to be an F of .35 which corresponds to an

exploitation rate of approximately 30%. The current strategy for stable yield advocates an exploitation rate in the range of 50% to 60% (Elner, 1982). If the exploitation of smaller animals were adopted the model predicts a lower $F_{0.1}$ which correspond to an annual exploitation of about 25% but with a slightly higher yield.

If fishing mortality could be focused on terminal males and the exploitation of non-terminals remained in the range of $F_{0.1}$, the yield could be expected to increase by an additional 20% A further benefit would be a reduction in the incidence of white crab in the landings. White crabs represent individuals recently molted into either a terminal or non-terminal status. A differential strategy would only reduce white crabs from the latter category. This would be expected to improve stability of landings under variable recruitment.,because more molt classes are being selected thus smoothing recruitment pulses over a number of seasons.

The following points concerning biological aspects of the model system should be kept in mind:

- Our results are for equilibrium situations. Recruitment variability, either temporal or stock dependent, cannot be examined with a yield per recruit model. However, exploitation strategies would have to be developed which take into account variations in the relative abundance of terminal animals that would result from trends in recruitment.
- Terminal animals are hypothesized to represent the actively reproductive portion of the population (Conan and Comeau 1986). If high fishing effort were directed entirely against terminal animals it would be likely to affect reproductive potential of the stock and hence recruitment.

A more realistic model would have to include a number of enhancements. For example, the molting frequency may be affected by fishing pressure. (Elner and Bailey 1986) Also, the fundamental biological parameters (growth and mortality) still require refinement. However, the values used in this study are the best available and are generally considered to be reasonable.

References.

Bailey, R. 1978. Status of snow crab (*Chionoecetes opilio*) stocks in the Gulf of St. Lawrence. CAFSAC Res. Doc. 78/27.

Conan, G.Y. and M. Comeau. 1986. Functional maturity and terminal molt of male snow crab,*Chionoecetes opilio*. Can. J. Fish. Aquat. Sci. 43:1710-1719.

Elner, R.W. 1982. An overview of the snow crab, *Chionoecetes opilio*,fishery in Atlantic Canada. *In* The International Symposium on the genus *Chionoecetes*. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. 83-10: 5-19.

Elner, R.W. and R.F.J.Bailey. 1986. Differential susceptibility of Atlantic snow crab, , stocks to management. p. 335-346. *In* G. S. Jamieson and N. Bourne [ed.] North Pacific Workshop on stock assessment and management of invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 1982.

Elner,R.W., R.E. Semple and E.M. Lachance. 1988. Assessment of the 1987 fishery for snow crab, *Chionoecetes opilio*, around the Atlantic coast of Cape Breton Island. CAFSAC Res. Doc. 88/J1.

Table 1 Yield per recruit from non-terminal, terminal and all males. FN is fishing mortality on non-terminal males and FT is on terminal. Selectivity corresponds to 95 mm CW limit.

FT	0	.2	.4	.6	.8	1.0	1.2	2.
FN		1.a	Non-terminal Male Yield					
0.0	.00	.00	.00	.00	.00	.00	.00	.00
0.2	9.96	9.96	9.96	9.96	9.96	9.96	9.96	9.96
0.4	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90
0.6	17.26	17.26	17.26	17.26	17.26	17.26	17.26	17.26
0.8	18.32	18.32	18.32	18.32	18.32	18.32	18.32	18.32
1.0	18.74	18.74	18.74	18.74	18.74	18.74	18.74	18.74
2.0	18.51	18.51	18.51	18.51	18.51	18.51	18.51	18.51
FN		1.b	Terminal Male Yield					
0.0	.00	6.42	8.74	9.99	10.78	11.34	11.76	12.72
0.2	.00	4.26	5.86	6.74	7.31	7.72	8.03	8.76
0.4	.00	2.94	4.09	4.74	5.18	5.49	5.73	6.32
0.6	.00	2.11	2.97	3.48	3.83	4.08	4.28	4.77
0.8	.00	1.57	2.25	2.67	2.95	3.17	3.33	3.75
1.0	.00	1.21	1.77	2.12	2.36	2.55	2.70	3.07
2.0	.00	.50	.80	1.00	1.15	1.27	1.37	1.62
FN		1.c	Total Male Yield					
0.0	.00	6.42	8.74	9.99	10.78	11.34	11.76	12.72
0.2	9.96	14.22	15.82	16.70	17.27	17.68	17.99	18.72
0.4	14.90	17.84	18.99	19.64	20.08	20.39	20.63	21.21
0.6	17.26	19.37	20.23	20.74	21.09	21.34	21.54	22.03
0.8	18.32	19.89	20.57	20.99	21.27	21.49	21.66	22.08
1.0	18.74	19.95	20.51	20.86	21.10	21.29	21.44	21.81
2.0	18.51	19.02	19.31	19.51	19.66	19.78	19.88	20.14

Table 2. Equilibrium male biomass for non-terminal, terminal and combined. FN is fishing mortality on non-terminal males and FT is on terminal. Selectivity corresponds to 95 mm CW limit.

FT	0	.2	.4	.6	.8	1.0	1.2	2.
FN			2.a Non-terminal Males					
0.0	105.4	105.4	105.4	105.4	105.4	105.4	105.4	105.4
0.2	89.5	89.5	89.5	89.5	89.5	89.5	89.5	89.5
0.4	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3
0.6	70.3	70.3	70.3	70.3	70.3	70.3	70.3	70.3
0.8	64.4	64.4	64.4	64.4	64.4	64.4	64.4	64.4
1.0	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1
2.0	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2
FN			2.b Terminal Males					
0.0	95.2	63.3	51.9	45.9	42.1	39.5	37.6	33.5
0.2	71.0	49.8	42.0	37.7	34.9	33.0	31.6	28.4
0.4	56.0	41.4	35.7	32.5	30.5	29.0	27.9	25.3
0.6	46.4	36.0	31.7	29.2	27.5	26.3	25.4	23.2
0.8	40.1	32.3	29.0	27.0	25.6	24.5	23.7	21.8
1.0	35.8	29.8	27.1	25.4	24.2	23.3	22.6	20.8
2.0	26.4	23.9	22.5	21.5	20.7	20.1	19.7	18.4
FN			2.c Total Males					
0.0	200.6	168.7	157.3	151.2	147.5	144.9	143.0	138.9
0.2	160.5	139.3	131.5	127.2	124.5	122.6	121.1	118.0
0.4	134.3	119.7	114.0	110.9	108.8	107.3	106.2	103.6
0.6	116.7	106.2	102.0	99.5	97.8	96.6	95.7	93.5
0.8	104.6	96.7	93.4	91.4	90.0	89.0	88.2	86.2
1.0	95.9	89.9	87.1	85.4	84.2	83.3	82.6	80.9
2.0	75.6	73.1	71.7	70.7	69.9	69.3	68.9	67.6

Table 3 Total yield per recruit and biomass per recruit. FN is fishing mortality on non-terminal males and FT is on terminal. Selectivity is approximately at the 75mm CW limit. Highlighted diagonal corresponds to a traditional yield per recruit with no distinction for terminal and non-terminal animals.

FT	0	.2	.4	.6	.8	1.0	1.2	2.
FN		3.a	Male	Yield				
0.0	0	8.16	11.05	12.55	13.46	14.08	14.52	15.50
0.2	11.01	15.80	17.54	18.46	19.02	19.40	19.67	20.28
0.4	14.88	17.89	19.02	19.62	19.99	20.24	20.42	20.83
0.6	16.00	18.03	18.81	19.23	19.49	19.67	19.80	20.09
0.8	16.14	17.58	18.15	18.46	18.65	18.79	18.89	19.10
1.0	15.95	17.03	17.47	17.70	17.85	17.96	18.03	18.21
2.0	14.96	15.34	15.50	15.60	15.65	15.70	15.73	15.79

FN		3.b	Male	Biomass				
0.0	200.6	160.1	145.8	138.6	134.3	131.5	129.5	125.5
0.2	132.6	108.9	100.3	95.9	93.2	91.5	90.2	87.7
0.4	94.2	79.2	73.6	70.7	69.0	67.8	67.0	65.3
0.6	71.2	61.2	57.3	55.3	54.1	53.2	52.6	51.4
0.8	56.8	49.7	46.8	45.3	44.4	43.8	43.3	42.4
1.0	47.3	41.9	39.8	38.6	37.9	37.4	37.1	36.3
2.0	27.3	25.4	24.6	24.2	23.9	23.7	23.6	23.3

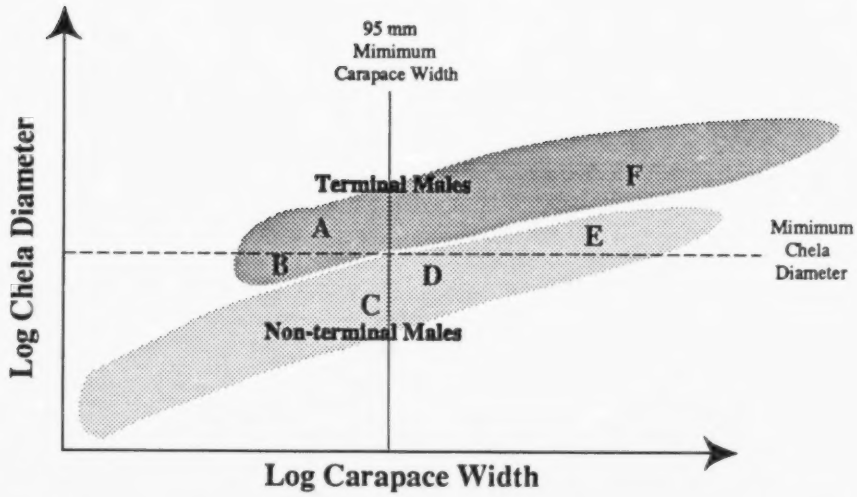

Fig. 1 Schematic of allometric relationship between carapace width and chela diameter for non-terminal (i.e. growing, "morphometrically immature") and terminal (i.e. non-growing, "morphometrically mature") male snow crabs. Components (D + E + F) are harvested under the current 95 mm minimum width regulations, leaving 'pygmy' males (A + B) unscathed but exploiting a non-terminal component (D + E). However, under a postulated minimum chela diameter regulation the components (A + F + E) would be harvested. The latter strategy would utilize a relatively greater proportion of the 'pygmies' and reduce landings of growing crabs.

Appendix A. Listing of snow crab yield per recruit program.

```
D:CRAB 1988 5 5 9 56

[ 0] DRIVE
[ 1] ST←'TERM SELECTIVITY ' DEFAULT ST
[ 2] SN←'NONS SELECTIVITY ' DEFAULT SN
[ 3] NRT←⍴,FRT←'F RANGE TERMS ' DEFAULT FRT
[ 4] NRN←⍴,FRN←'F RANGE NONS ' DEFAULT FRN
[ 5] M←'NAT. MORT. ' DEFAULT M
[ 6] PM←'PROB MOLTING ' DEFAULT PM
[ 7] PT←'PROB GOING TERMINAL ' DEFAULT PT
[ 8] B←Y←(NRN,NRT,3)⍴IT←0
[ 9] TLOOP:→(NRT<IT←IT+1)/OP
[10] FT←ST×FRT[IT]
[11] IN←0
[12] NLOOP:→(NRN<IN←IN+1)/TLOOP
[13] FN←SN×FRN[IN]
[14] INF←100÷I←0
[15] Z←ZZ←ZM←ZT←(⍴PT)⍴0
[16] TOP:→((⍴PM)<I←I+1)/LLOOP
[17] ZZ[I]←(INF×*-M[I]+FN[I])÷((PM[I]+PT[I])+(1-PM[I]+PT[I])×1-*-M[I]+FN[I])
[18] ZT[I]←ZZ[I]×PT[I]÷1-*-M[I]+FT[I]
[19] INF←ZM[I]←ZZ[I]×PM[I]
[20] Z[I]←ZT[I]+ZZ[I]××M[I]+FN[I]
[21] →TOP
[22] LLOOP:YT←W+.×CT←FT×ZT×(1-*-FT+M)÷FT+M ⍝ CATCH AND YIELD OF TERMS
[23] YN←W+.×CN←FN×(Z-ZT)×(1-*-FN+M)÷FN+M ⍝ CATCH AND YIELD OF NONS
[24] Y[IN;IT;]←YN,YT,YT+YN
[25] BT←W+.×ZT
[26] BN←W+.×Z-ZT
[27] B[IN;IT;]←BN,BT,BN+BT
[28] →NLOOP
[29] OP:2 ROUND Y[;;3]
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